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THE DETECTION OF TOXIC VAPOURS IN THE ATMOSPHERE BY INFRARED SPECTROPHOTOMETRY. IV, ATMOSPHERIC SAMPLES FROM H.M.SHIPS [R]

by

P.A. Hollingdale-Smith and L.C. Thomas

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Chemical Defence Establishment,
Porton Down,
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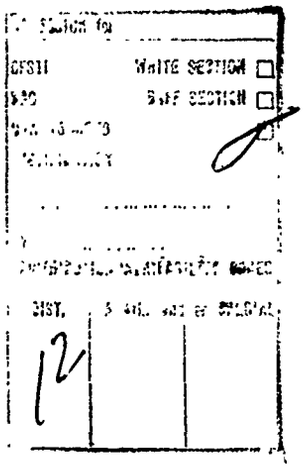

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THE DETECTION OF TOXIC VAPOURS IN THE ATMOSPHERE BY INFRARED SPECTROPHOTOMETRY. IV, ATMOSPHERIC SAMPLES FROM H.M. SHIPS

by

P.A. HOLLINGDALE-SMITH [redacted] L.C. THOMAS

SUMMARY

Samples of air taken aboard selected types of H.M. ships have been analysed by infrared spectrophotometry using long optical-path gas cells. Nine gases, acetylene, carbon dioxide, carbon monoxide, carbonyl sulphide, ethylene, Freon 12, hydrocarbons, hydrogen cyanide, and methane were detected at concentrations high enough to be determined quantitatively and traces of several other gases were also identified. In addition, there were a number of absorption bands, in the spectra obtained from some samples, which could not be identified unequivocally.

In surface vessels, under 'shut-down' conditions, and in a submarine during submersion, the concentrations of some contaminants built up to a high level. Any chemical entering the citadel was dispersed to all parts of the air circulation system.

It is concluded that no interference with detection devices at present under investigation is likely from any of the compounds detected at the concentrations measured.

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LCT/PAHS/SSE

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THE DETECTION OF TOXIC VAPOURS IN THE ATMOSPHERE BY INFRARED SPECTROPHOTOMETRY. IV. ATMOSPHERIC SAMPLES FROM H.M. SHIPS

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INTRODUCTION

It is an essential requirement for any device developed for the detection of chemical agents that it should not respond to less toxic or harmless constituents of the atmosphere. An integral part of the detection research programme is thus the determination of the qualitative and quantitative composition of the atmosphere under normal and "battle" conditions. A report on contaminants present in military environments has already appeared (1), and this report extends the data to analyses carried out in selected types of naval vessels.

One of the special C.W. detection problems in naval vessels will be the possibility of interference arising from the build up of atmospheric pollution within the citadel during 'shut-down' periods. Special attention has therefore been paid to this problem. During peace-time operation of H.M. ships these conditions occur only during training exercises. Air samples have been taken both during the limited 'shut-down' periods arising during routine working-up exercises, and also during the much more prolonged period which was part of exercise "Glossop" (2).

In addition to the special case of pollution build up during 'shut-down' conditions, there are other sources of air pollution peculiar to H.M. ships. These include funnel gases, the effluent from the firing of surface-to-air missiles such as 'Sea-Cat' and the pollution arising from aircraft exhausts during the operation of aircraft carriers. Samples have been taken of all these atmospheres.

These air samples have been analysed by infrared spectrophotometry using long optical-path gas cells and procedures which have been described in earlier reports (3, 4).

EXPERIMENTAL

Air samples were collected in laminated plastic bags by means of battery operated diaphragm pumps. These samples were analysed within twenty-four hours wherever possible. Samples were taken in H.M.S. Tartar (Tribal Class), H.M.S. Devonshire (County Class) and H.M.S. Hermes (Aircraft Carrier) during working up exercises, and in H.M.S. Penelope (Leander Class) during exercise "Glossop". Samples were also taken in H.M.S. Hampshire (County Class) during firing trials of 'Sea-Slug' and 'Sea-Cat' missiles and in H.M.S. Artemis (Submarine) during exercises.

Infrared absorption spectra of these atmospheric samples were recorded over the wavelength region 2 - 15 microns at 760 mm Hg pressure with the optical path in the absorption cells set at 40 m. When the sample was not large enough to fill the cell to 760 mm pressure, the highest attainable pressure was used and recorded and the results were subsequently corrected to 760 mm. The presence of water vapour in the samples was compensated in the spectra by the use of wet nitrogen in the reference cell (1, 4).

Quantitative analyses were performed by measuring the optical density of selected characteristic absorption bands and comparing these with calibration curves. Qualitative analyses were carried out by comparing the spectra of the samples with spectra of pure compounds.

RESULTS

(a) H.M.S. Penelope

Two sets of samples were taken within the citadel, one a series of single random samples, the other a series of sequential samples taken at intervals at selected spots. This second series was taken at points, such as the operations room, where the build up of atmospheric pollutants was expected to be especially severe. Quantitative measurements have been made for carbon dioxide, carbon monoxide, carbonyl sulphide (COS), Freon 12 (CCl_2F_2) and methane. In addition, the presence of low concentrations of a number of other gases has been noted. The analyses for these two series are recorded in Tables 1 and 2.

In addition to the absorption bands attributable to the compounds listed in these two Tables, a number of absorption bands have been observed in some of these spectra which cannot be assigned unequivocally to any compound. A list of these bands, together with some possible assignments for them, is given in Table 3.

(b) H.M.S. Tartar and Devonshire

The analyses of four samples taken aboard H.M.S. Tartar are recorded in Table 4. Table 5 records the analyses of seven samples taken aboard H.M.S. Devonshire. Unidentified absorption bands from the spectra of samples taken aboard H.M.S. Devonshire are listed in Table 6.

(c) H.M.S. Artemis

The first sample was taken while H.M.S. Artemis was running on the surface with full ventilation in operation. All further samples, except No.6, were taken in the after torpedo stowage position. No.6 was taken in the ASDIC room. The analyses of these samples are reported in Table 7. The submarine submerged at 0930 hours and the increase in concentration of carbon dioxide, carbon monoxide, Freon 12, hydrocarbons and methane with time, which is apparent from Table 7 is illustrated, for carbon dioxide and hydrocarbons, in Figures 1 and 2.

(d) H.M.S. Hermes

Samples were taken, both at deck level and from the Gun Direction Platform, during aircraft take-off and while aircraft were parked, with their engines running, prior to take-off. The analyses are reported in Table 8. There were no unidentified absorption bands in the spectra of these samples.

(e) H.M.S. Hampshire

Air sampling was performed at several points below deck, and also on deck during the firing of both 'Sea Slug' and 'Sea Cat' missiles. The analyses are reported in Table 9.

DISCUSSION OF RESULTS

For convenience of reference the maximum concentration of pollutants detected in the naval samples are collected together in Table 10, which also includes the overall maxima found to date including the military samples (1). Table 11 lists those compounds which have been identified at concentrations too low for quantitative analysis.

Five gases, carbon dioxide, carbon monoxide, carbonyl sulphide, Freon 12 and methane, were detected at concentrations which were sufficiently high for quantitative analysis. Water vapour was present in all samples but no attempt was made to make quantitative measurements of the humidity. Other major components of the air, such as oxygen and nitrogen, are not detected in infrared spectra.

The presence of methyl alcohol was detected in most of the samples taken within the citadel of H.M.S. Penelope after 1300 hours on 13.10.65, but not before that time. Its ubiquitous appearance shows that once a substance appears in the air of the citadel at one point it is dispersed to all parts. This is also illustrated by the analyses of Freon 12. Here the source of contamination was obviously a slight leak in the refrigeration space, but this gas was found throughout the citadel. Of the other gases which were identified, hydrocarbons probably originated from a fuel leakage. Methyl ethyl ketone, tetrahydrofuran and toluene are all industrial solvents and their presence probably originated from paint or a similar source.

The analyses of the sequential samples, reported in Table 2, show that there is a build up of both carbon monoxide and carbon dioxide where people are working in confined quarters.

It is noteworthy that no oxides of nitrogen were detected in any of the samples, even after gunfire.

Carbon dioxide concentrations found in the samples from H.M.S. Tartar (Table 4) were much lower than those in samples from H.M.S. Penelope. However, in this test no samples were taken in crowded spaces and the period of citadel 'shut down' was very limited. The concentrations thus did not have the same opportunity to build up. In contrast the concentration of Freon 12 was so high that it was obvious that a major leak was present. This was subsequently located.

In H.M.S. Devonshire also, samples were not taken in any of the crowded working areas to avoid interference with other trials which were in progress. Freon 12 was absent from the samples which were taken (Table 5) except for a low concentration in the refrigerator space. The two samples taken in the citadel near the turret entrance during the firing of the guns showed an increased carbon monoxide concentration. This suggests that fumes from the turret were entering the citadel, and this suggestion is supported by the strong smell of burning cordite which was noticed at the sampling point while the samples were being taken. Any such leakage of fumes from the turret would have increased the overall contamination of citadel air during prolonged 'shut-down' periods. Once again no oxides of nitrogen were detected in these samples.

The unidentified bands in the spectra of samples from H.M.S. Penelope and Devonshire (Tables 3 and 6) were of low intensity and therefore unlikely to arise from vapour concentrations which could affect detection devices. However this cannot be certain until the bands are identified, and the library of reference spectra is being expanded, as samples become available, with the object of identifying all these bands.

The air samples taken aboard H.M.S. Artemis (Table 7) in an antisubmarine exercise (CASEX exercise), show a progressive, virtually linear, increase in contaminant concentration once the submarine had submerged. This increase is illustrated in Figures 1 and 2. The concentrations of all contaminants were still increasing when the submarine surfaced after seven hours.

None of the samples taken on H.M.S. Hermes (Table 8) contained sufficient pollutants to interfere with C.W. detectors currently under investigation. Some of the samples taken on H.M.S. Hampshire (Table 9) contained fairly high concentrations of carbon monoxide as the result of Sea Slug firing. Apart from this it is noteworthy that the highest levels of pollution were found in key areas of the citadel such as the Operations Room, the Main Communications Office and the Radar Office.

Table 10 summarises the pollutants encountered in naval environments and also provides an overall summary of pollution analyses to date. This provides a qualitative and quantitative guide to pollutants which may be encountered in "battle" atmospheres and is intended for the guidance of workers developing detection equipment.

CONCLUSIONS

1. No interference with detection systems at present under investigation is likely from any of the compounds detected in naval vessels at the concentrations measured.

2. Any vapour entering a citadel is dispersed to all parts within the citadel air circulation system. The citadel, in its present form, therefore appears especially vulnerable to breach of its defences by a chemical agent.

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TABLE 1

RANDOM SAMPLES FROM H.M.S. PENELOPE AFTER "SHUT-DOWN" AT

0800 hr 13.10.65

Date	Time	Position	Gas concentrations, p.p.m.					Other gases			
			CO	CO_2	COS	Freon	CH_4	MA	EA	MEK	Tol
13/10	0940	Boiler room (50% ventilation)	n.d.	535	0.01	0.0[illegible]	1.3	-	-	+	-
	1000	Engine room (50% ventilation)	n.d.	493	n.d.	n.d.	1.1	-	-	-	-
	1025	" " (no ventilation)	n.d.	376	n.d.	n.d.	1.7	-	+	-	-
	1120	Main communications office	n.d.*	200*	n.d.*	n.d.*	0.8*	-	-	-	-
	1307	Forward repair party position	33	2170	0.10	1.1	2.2	+	-	-	-
	1325	Shell room	23	1190	0.07	0.18	1.5	-	-	-	-
	1400	Diesel room	n.d.	840	0.01	0.34	1.7	+	-	+	-**
	1445	Cabin flat near A.F.U.	23	1700	0.07	3.7	2.0	+	+	+	-
	1540	Refrigerator space	n.d.	2600	0.10	40	2.3	-	+	-	-
14/10	0425	Shell room	36*	880*	0.14*	4.4*	2.0*	-	-	-	-
	0435	Forward repair party position	45*	3600*	0.18*	14.4*	2.6*	+	-	+	+
	0520	Engine room (50% ventilation)	n.d.*	400*	n.d.*	0.4*	1.7*	+	-	+	+
	0530	Diesel room	43	2970	0.14	12.0	2.7	+	-	+	+
	0545	Boiler room (50% ventilation)	n.d.	360	n.d.	0.28	1.2	+	-	-	+
	0810	Junior ratings galley	32	2940	0.11	6.6	3.0	+	-	+	+
	1155	Cabin flat near A.F.U.	30	2240	0.09	5.6	2.8	+	-	+	+
	1450	Shell room immediately after shoot	34	4300	0.14	2.7	2.0	+	-	+	+
15/10	0740	Shell room	39	4025	0.17	3.6	2.2	-	-	+	+
	0745	Forward repair party position	33	3060	0.16	7.1	3.0	+	-	+	+
	0755	Engine room (no ventilation).	n.d.	600	0.02	0.13	0.7	+	-	+	+††
	0800	Boiler room (no ventilation)	n.d.*	1000*	n.d.*	0.8*	2.1*	-	-	+	+
	0805	Diesel room	34	3350	0.17	9.2	2.9	+	-	+	+**
	0820	Cabin flat near A.F.U.	28	2850	0.10	7.9	2.8	-	-	-	+
	0825	Cabin flat - heads	28	2140	0.10	8.2	2.3	+	-	-	+

n.d. = not detected.
* = sample damaged in transit.
\+ = detected at level too low for accurate measurement.
EA = ethyl alcohol
MEK = methyl ethyl ketone
Tol = toluene
MA = methyl alcohol
†† = tetrahydrofuran
** = hydrocarbons

TABLE 2

SEQUENTIAL SAMPLES FROM H.M.S. PENELOPE AFTER SHUT-DOWN AT 0800 hr, 13.10.65

Date	Time	Position	Gas Concentration, p.p.m.					Other gases			
			CO	CO_2	COS	Freon	CH_4	MA	EA	MEK	Tol
13/10	1100	Asdic room	31	2250	0.12	0.5	2.3	-	-	-	-
	1330	" "	36	2800	0.12	2.4	2.0	+	-	-	-
	1505	" "	†	†	†	†	†	†	†	+	†
	1620	" "	26	1520	0.07	2.3	1.8	+	-	-	-
14/10	0450	" "	18*	1140*	0.07*	6.0*	1.9*	-	-	+	-
	0800	" "	†	†	†	†	†	†	†	+	†
	1055	" "	33	2380	0.11	4.3	2.6	-	-	+	+
	1405	" "	47	3440	0.15	5.7	3.2	+	-	+	+
	1535	" "	36	3400	0.12	5.7	3.1	+	-	-	+
15/10	0840	" "	43	3340	0.18	7.5	3.2	+	-	+	+
13/10	1110	Operations Room	32*	1340*	0.10*	2.0*	2.3*	-	-	-	-
	1335	" "	32	2450	0.09	4.6	2.1	+	+	-	-
	1510	" "	15	1050	0.02	2.4	1.4	-	-	-	-
	1625	" "	36	2820	0.14	5.6	2.0	+	-	-	+
14/10	0455	" "	35	2500	0.12	11.6	2.7	+	-	+	+
	0805	" "	37	2680	0.11	8.5	2.7	+	-	+	+
	1100	" "	43	3020	0.14	7.4	2.4	+	-	+	+
	1410	" "	45	3970	0.15	9.7	2.8	+	-	+	+
	1540	" "	47	3880	0.16	8.8	2.7	+	-	-	-
15/10	0845	" "	43	2800	0.14	10.5	2.7	+	-	+	+
13/10	1140	H.Q 1	30*	1125*	0.08*	1.0*	2.4*	-	-	-	-
	1345	"	24	2020	0.07	1.9	1.3	+	+	-	-
	1520	"	27	2640	0.13	3.2	1.8	+	-	+	-
	1630	"	†	†	†	†	†	†	†	†	†
14/10	0510	"	26	2760	0.12	8.0	2.3	+	-	-	+
	0815	"	40*	2450*	0.10*	5.6*	1.8*	+	-	-	-
	1105	"	50	3770	0.20	6.3	3.0	+	-	+	+
	1420	"	30	2380	0.10	3.4	2.7	+	-	+	+
	1550	"	47	3760	0.15	4.9	2.7	+	-	+	+**

* Sample damaged in transit.

† Sample destroyed in transit.

MA = Methyl alcohol.

EA = Ethyl alcohol.

MEK = methyl ethyl ketone.

Tol = toluene.

** = hydrocarbons.

+ = detected but not estimated.

/Continued.

TABLE 2 (Cont'd).

Date	Time	Position	Gas Concentration, p.p.m.					Other gases			
			CO	CO_2	COS	Freon	CH_4	MA	EA	MEK	Tol
12/10	0855	H.Q.1	36	2900	0.15	7.3	2.6	+	-	+	+
13/10	1415	After repair-party position	22	1050	0.04	0.6	1.7	+	-	-	-
14/10	0500	" " "	32	3675	0.20	7.2	2.1	+	-	+	+
	0910	" " "	32	3320	0.16	4.5	2.9	+	+	-	+
	0915	" " "	50	5320	0.23	7.9	4.3	+	-	+	+
	1115	" " "	43*	2400*	0.16*	5.0*	3.0*	+	-	+	+
	1425	" " "	59*	6200*	0.20*	7.0*	3.9*	+	-	-	+
	1555	" " "	48	4030	0.18	4.4	3.0	+	-	+	+
15/10	0810	" " "	35	4600	0.22	4.4	2.5	+	-	+	+

* Sample damaged in transit.

† Sample destroyed in transit.

MA = Methyl alcohol.

EA = Ethyl alcohol.

MEK = methyl ethyl ketone.

Tol = toluene.

** = hydrocarbons.

+ = detected but not estimated.

TABLE 3

UNIDENTIFIED ABSORPTION BANDS IN H.M.S. PENELOPE SAMPLES

Band wavelength (microns)	Possible origin
5.75	Carbonyl (C=O) ? esters
7.35	CH in CH_3, CHO, $\geq$C-OH, etc.
7.85	m-cresol
8.1	esters (C-O-)
10.1	CH_2=CH-, POC, sat. ring, etc.
11.75	aromatic, $\geq$C=CH- etc.
12.45	" "
12.85	m-cresol
13.05	m-cresol

TABLE 4

SAMPLES FROM H.M.S. TARTAR (27.5.65)

Position	Gas concentration p.p.m.					Other gases		
	CO	CO_2	COS	Freon	CH_4	MA	HA	THF
Refrigerator space	n.d.	440	n.d.	500	0.8	-	-	-
Boiler room	17	830	0.08	0.3	1.3	+	+	+
On deck	n.d.	200	n.d.	n.d.	1.8	+	-	-
Heads	10	680	0.05	0.6	0.3	++	+	+

n.d. = not detected

M.A. = methyl alcohol

H.A. = higher alcohols - butanol and/or cyclohexanol.

T.H.F. = tetrahydrofuran.

+ = detected but not estimated

++ = not estimated but higher concentration than +

TABLE 5

SAMPLES FROM H.M.S. DEVONSHIRE (1.6.65)

Position	Gas concentration p.p.m.				
	CO	CO_2	COS	Freon	CH_4
Compartment 2L	n.d.	1100	0 06	n.d.	1.4
Compartment 2M	n.d.	1425	0.05	n.d.	1.1
Turbine space	n.d.	2025	0.09	n.d	0.6
Citadel near turret entrance	9.6	550	n.d.	n.d.	0.9
Citadel near turret entrance	9.6	320	n.d.	n.d.	0.7
Galley	n.d.	350	n.d.	n d.	0.4
Refrigerator space	n.d.	900	n.d.	3.2	1.2.

n.d. = not detected.

TABLE 6

UNIDENTIFIED ABSORPTION BANDS FROM H.M.S. DEVONSHIRE SAMPLES

Band wavelength (microns)	Possible origin
3.1	OH, NH
3.25	Pyridine, $C=CH_2$
12.6)	
12.8)	Aromatic, C-Cl, etc.
12.9)	

TABLE 7

SAMPLES FROM H.M.S. ARTEMIS (19.7.66)

Sample No.	Time (hr)	CO_2 (%)	Freon (%)	CO (p.p.m)	CH_4 (p.p.m.)	Hydrocarbons (p.p.m.)
1	0755	0.16	1.4 ppm.	4	2.5	3.4
2	1030	0.29	0.07	10	4.4	17
3	1125	0.43	0.08	20	6.1	23
4	1240	0.69	0.09	26	8.4	34
5	1325	0 78	0.09	50	9.4	42
6	1345	0.81	0 09	48	9.9	35
7	1430	0.91	0.12	39	10.3	53
8	1530	1.08	0.11	38	11.5	53
9	1630	1.18	0.11	43	12.3	68

In addition all samples showed traces of NH_3 and samples 2 - 9 inclusive showed traces of methanol and toluene.

Dived 0930 hr. Surfaced 1645 hr.

TABLE 8

SAMPLES FROM H.M.S. HERMES (19.1.67)

Sample Point	Gas Concentrations in p.p.m.						Remarks
	CO_2	CO	CH_4	Hydrocarbons	NH_3	Others	
Deck level	300	6	1.6	1.4	Trace	-	Gannet take off
Gun direction platform	220	n.d.	1.6	1.4	Trace	Ethanol?	Gannet take off
Deck level	270	n.d.	1.0	0.8	Trace	Ethanol?	Gannet and Buccaneer take off
Gun direction platform	240	n.d.	1.5	1.0	Trace	Ethanol?	Gannet and Buccaneer take off
Deck level	330	n.d.	1.5	0.9	Trace	Ethanol?	Gannets and Buccaneers with engines running
Gun direction platform	240	n.d.	2.4	1.5	Trace	Ethanol?	Gannets and Buccaneers with engines running
Gun direction platform	250	n.d.	1.4	1.1	Trace	-	Gannets and Buccaneers with engines running
Deck level	515	n.d.	1.1	1.1	Trace	-	Buccaneer take off
Gun direction platform	470	n.d.	1.5	0.8	Trace	Acetone	Buccaneer take off
Deck level	220	20	1.8	1.5	Trace	Ethylene 0.2; Acetylene 0.2; Ethanol?	Gannet and Buccaneer take off

n.d. = not detected.

? = bands insufficiently intense for unequivocal identification.

TABLE 9

SAMPLES FROM H.M.S. HAMPSHIRE (21 - 29.3.66)

Position and other details	Gas concentrations, p.p.m.				Hydro-carbons (As hexane)
	CO_2	CO	CH_4	Others	
Upper deck (strong smell of fuel oil)	350	n.d.	2.2	-	1.4
Operations Room	1400	n.d.	2.2	Freon 12 1.2 p.p.m.; 1,1,1-trichlorethane	2.6
Crew's galley	600	n.d.	1.3	Formic acid	2.3
Upper deck, in air stream from machinery space exhaust fan	270	n.d.	2.2	Formic acid; HCN 0.8 p.p.m.	1.3
Port side, 1st Seaslug firing	420	250	2.3		1.2
Starboard side, 1st Seaslug firing	350	200	1.9		0.7
Stern, 1st Seaslug firing	320	130	2.1		0.8
Stern, 2nd Seaslug firing	340	130	2.3		1.3
Port side, 3rd Seaslug firing	750	400	2.7		2.3
Stern, 3rd Seaslug firing	600	270	2.3		1.0
Main communications office	1600	n.d.	2.7	Freon 12 1.0 p.p.m.; 1,1,1-trichlorethane	2.5
Crew's Mess Hall	350	n.d.	2.6	Formic acid	1.3
Radar Office	1100	n.d.	1.4	Freon 12 0.3 p.p.m.; 1,1,1-trichlorethane. Dichloromethane.	2.1
Forward cooling plant	410	n.d.	2.3	Freon 12 2.7 p.p.m.	1.3
Port passage 2J (smell resembling chlorinated aromatics)	340	n.d.	2.1		1.6
Gas turbine machinery space	460	n.d.	2.7		1.8
In hangar, immediately after helicopter had been put in	500	n.d.	1.8		1.5
2E mess deck	900	n.d.	2.7		1.5
3 Deck, compartment R (noticeable taste of SO_2)	500	n.d.	1.4		1.5
2 Deck, just outside refrigeration machinery space	500	n.d.	2.6	Formic acid.	1.7
2 Deck, outside blower compartment	500	n.d.	1.8	Formic acid.	1.0
By Seacat launcher. 1st firing	1100	16	2.1	Formic acid.	1.7
By Seacat launcher. 1st firing	500	16	1.4		1.4
By Seacat launcher. 2nd firing	500	13	2.2		0.7
By Seacat launcher. 2nd firing	550	13	2.2		1.2
By Seacat launcher. 3rd firing	550	18	1.8		0.9
By Seacat launcher. 3rd firing	700	13	2.2		1.1

n.d. = not detected.

TABLE 10

MAXIMUM OBSERVED CONCENTRATIONS OF ATMOSPHERIC POLLUTANTS

Compound	Maximum concentration p.p.m.		Source of maximum concentration
	Naval samples	Naval and military samples.	
Acetylene	0.2	7.0	Brush fire
Ammonia	Trace	10.0	Decomposing animals
Carbon dioxide	11,800	12,000	Brush fire
Carbon monoxide	400	1,100	Brush fire
Carbonyl Sulphide	0.18	0.18	Shut down citadel
Ethanol	Trace	11.0	Decomposing animals
Ethylene	0.2	14.5	Brush fire
Freon 12	1200	1200	Submarine
Hydrocarbons*	68	68	Submarine
Hydrogen cyanide	0.8	7.5	Brush fire
Methane	12.3	250	Brush fire
Methanol	Trace	60	Brush fire
Nitrous oxide	n.d.	0.3	Decomposing animals

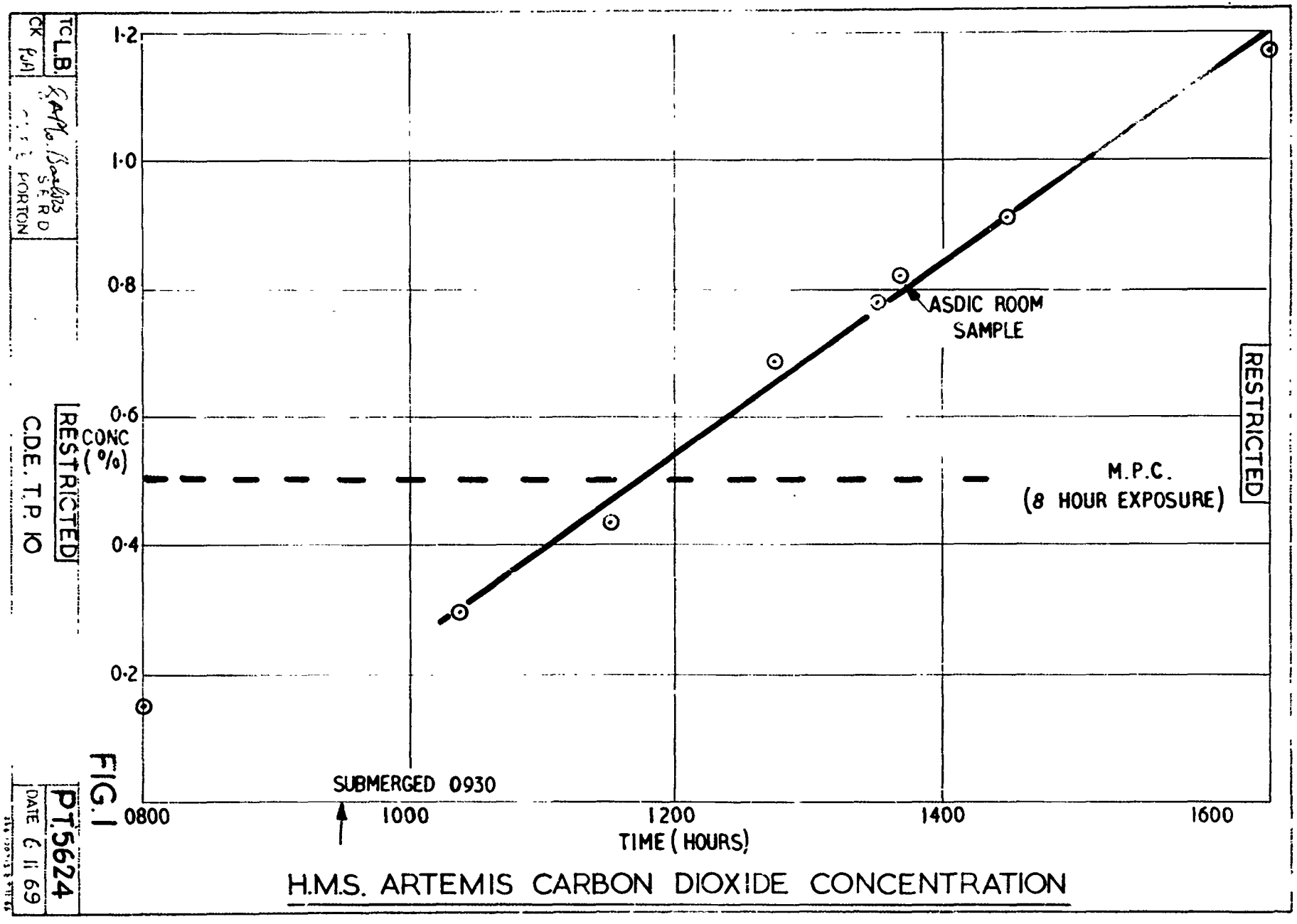
* Calculated as hexane

n.d. = not detected.

TABLE 11

COMPOUNDS IDENTIFIED IN "BATTLE" ATMOSPHERES AT CONCENTRATIONS TOO LOW TO MEASURE

Acetone
Alcohols (butanol and/or cyclohexanol)
Aldehydes
Dichloromethane
Formic acid
Methyl ethyl ketone
Tetrahydrofuran
Toluene
1,1,1-Trichloroethylene


TC L.B.
CK PJA
RESTRICTED
C.D.E. T.P. 10
FIG. 1
PT.5624
DATE 6 11 69
1·2
1·0
0·8
0·6
0·4
0·2
CONC (%)
ASDIC ROOM SAMPLE
M.P.C.
(8 HOUR EXPOSURE)
RESTRICTED
SUBMERGED 0930
0800
1000
1200
1400
1600
TIME (HOURS)
H.M.S. ARTEMIS CARBON DIOXIDE CONCENTRATION

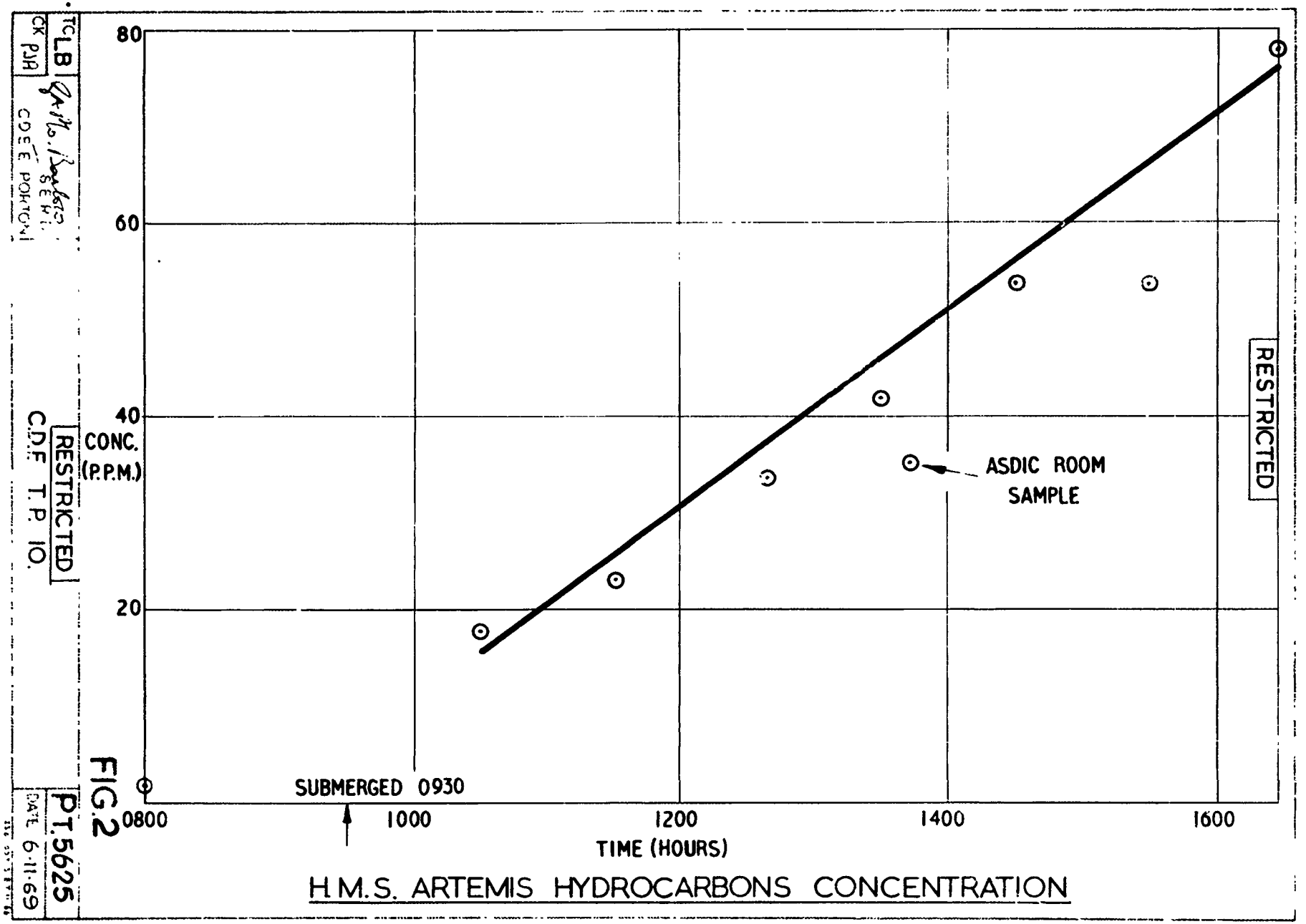


FIG.2

H.M.S. ARTEMIS HYDROCARBONS CONCENTRATION

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